Performance Evaluation and Modeling of Wireless Personal Area Networks

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Outline

• Technology Challenges in Wireless Personal Area Networks (WPANs)
  – Interoperability, interference, support of multimedia applications
• Formal Modeling of Bluetooth
• Coexistence Performance Evaluation of WPANs and WLANs in the 2.4 GHz band.
  – Simulation models (MAC, PHY, Channel)
  – Analysis and Results
• Coexistence Mechanisms
• Conclusions
Key Challenges in WPANs

• Non-interoperable protocols and multiple industry specifications:
  – Bluetooth, HomeRF, IEEE 802.11, DECT, IEEE 802.15 (TG1, TG3, TG4), HIPERLAN.

• Interference in the unlicensed bands:
  – 2.4 GHz ISM Band: Bluetooth, HomeRF, IEEE 802.11, IEEE 802.11-b devices operating in the same environment lead to significant performance degradation in WPAN and WLAN services.
  – 5 GHz Band: HIPERLAN and IEEE 802.11a, IEEE 802.17, weather radar.
Bluetooth

- Wireless Personal Area Networking
- 1 Mb/s Total Data Rate with TDMA structure
  - Frequency hopping on a packet basis
- Approximately 10 m Range
  - 1 mw to 100 mw Transmitter Power
  - Low Cost Radio Receivers
- Initially Designed for One Hop Operation
  - Star-like Topology
  - 1 Master and up to 7 Slaves
  - Scatternets to allow multiple hop networks
- Voice and Data Links
IEEE 802.11b

- Wireless Local Area Network (WLAN)
  - Wireless Ethernet
- 1, 2, 5.5, and 11 Mb/s
  - Direct Sequence Spread Spectrum
  - Complementary Code Keying
- Carrier Sense Multiple Access with Collision Avoidance
  - Also virtual carrier sense using request-to-send (RTS) and clear-to-send (CTS) message
- Range on the order of 100 m
  - Up to 1 W Transmitter Power
• Allows formal modeling and (with additional tools) verification of a protocol - Bluetooth
  – Ensure that IEEE 802.15.1 (WPAN) specifications are correct
• Provides a hierarchical view of the protocol
• Can be used to generate a software implementation
• Test scenario creation
Sample SDL Charts
System Simulation Modeling

- Detailed DSP Transmitter and Receiver Simulation Models (stage 1 - NIST)
- Link Budget Analysis (stage 0 - Mobilian)

Parameters IN
Main Packet: Type, Power, Frequency, distance(tx,rx)
Interference Packet: Type, Power, Frequency, distance(tx,rx), Time Offset
Spectral Domain
• Additive White Gaussian Noise, multipath fading
• Path loss model

\[ L_p = \begin{cases} 
32.45 + 20 \log(f \cdot d) & d < 8m \\
58.3 + 33 \log(d / 8) & \text{otherwise}
\end{cases} \]

• Received power and SIR depend on topology and device parameters:

\[ P_R = P_T - L_p \]

\[ SIR = P_R - P_I \]
• DSP based implementation of transceivers
• Design using typical parameters (goal is to remain non-implementation specific)
• Bluetooth
  – Non-coherent Limiter Discriminator receiver, Viterbi receiver with channel estimation and equalization
• IEEE 802.11
  – Direct Sequence Spread Spectrum (1 Mbits/s)
  – Complementary Code Keying (11 Mbits/s)
  – Frequency Hopping (1 Mbits/s)
• MAC behavioral implementation for Bluetooth and IEEE 802.11 (connection mode)
• Frequency hopping
• Error detection and correction
  – Different error correction schemes applied to packet segments (Bluetooth)
  – FCS (802.11)
• Performance statistics collection
  – Access delay, packet loss, residual error, throughput
Simulation Scenario

Impact of WLAN Interference on Bluetooth Performance

Impact of Bluetooth Interference on WLAN Performance

Traffic Distribution for WLAN and BT (LAN)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offered Load</td>
<td>30% of Channel Capacity</td>
</tr>
<tr>
<td>Packet Size</td>
<td>Geometric Distr. Mean 368 bytes</td>
</tr>
</tbody>
</table>

Data

ACK

Statistics Collection Points
Impact of Interference on Packet Loss

Distance of Receiver (BT, WLAN) from Interference Source (BT, WLAN) (meters)

Probability of Packet Loss

- WLAN (11 Mbits/s) w/ BT Voice Interference
- BT LAN w/ WLAN (11 Mbits/s) Interference
- BT Voice w/ WLAN (11 Mbits/s) Interference
- WLAN (11 Mbits/s) w/ BT LAN Interference
Impact of Interference on MAC Access Delay

- **WLAN (11 Mbits/s) w/ BT LAN Interference**
- **BT LAN w/ WLAN (11 Mbits/s) Interference**

**Mean Access Delay (seconds)**

**Distance of Receiver (BT, WLAN) from Interference Source (BT, WLAN) (meters)**
Coexistence Mechanisms

• Collaborative:
  – TDMA solution for scheduling Bluetooth and 802.11 packets on the same device.
  – Notch filtering in 802.11 receiver to remove Bluetooth

• Non-collaborative:
  – Adaptive frequency hopping
  – Varying packet size, data rates, encapsulation
  – MAC scheduling
  – Distributed power control
Packet Loss for Bluetooth:
Traffic: DM1; 30% Offered Load

Distance of WLAN Mobile from Bluetooth Slave (meters)

- No coexistence scheme
- Ptx = 100 mW
- Adaptive Power Control
- Ptx = 80 mW
- MAC Packet Scheduling
- Ptx = 8 mW
- Ptx = 3 mW
Access Delay for Bluetooth:
Traffic: DM1; 30% Offered Load
Conclusions

• Bluetooth and 802.11b can cause significant interference to each other

• Coexistence mechanisms can substantially reduce this problem
  – Ongoing work required for Bluetooth voice packets
  – Proposals are being evaluated and refined in IEEE 802.15 Task Group 2
    – Standard practices for operations are being developed

• Having unambiguous specifications is essential
  – Submitted SDLs for Bluetooth to be included as an Annex to IEEE 802.15 TG1 specifications.

• Preparing to release simulation tools to the public.